GSRP FINAL REPORT

James English (NGT9-2)

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Degree Awarded

Doctor of Philosophy in Electrical Engineering

Dissertation Title

Free-Swinging Failure Tolerance for Robotic Manipulators

Project Summary

Under this GSRP fellowship, software-based failure-tolerance techniques were developed for robotic manipulators. The focus was on failures characterized by the loss of actuator torque at a joint, called free-swinging failures. The research results spanned many aspects of the free-swinging failure-tolerance problem, from preparing for an expected failure to discovery of postfailure capabilities to establishing efficient methods to realize those capabilities. Developed algorithms were verified using computer-based dynamic simulations, and these were further verified using hardware experiments at Johnson Space Center.

Results

It was found that substantial free-swinging fault tolerance can be instilled in kinematically redundant manipulators using a software-based approach. (Kinematically redundant manipulators are those with more joints than the minimum required.) It was established that gravitational- or acceleration-based forces can be used to 1) reduce the likelihood of a failure, 2) reduce the immediate negative impact of a failure, such as collision, and 3) position the failed joint after a failure. Kinematic redundancy in the arm allows the first two objectives to be accomplished while using the hand as desired, and with the third objective it allows tasks to be completed after a failure. The results of simulations and hardware experiments testing the developed techniques showed them to be efficient and valid.

Benefits to NASA and the Public

General, tested algorithms are now available for improving the dependability of robotic manipulators in remote and hazardous environments. With these algorithms, operation can potentially be continued after a free-swinging joint failure. Without such a remedy, a free-swinging failure could result in a complete failure of a mission. This is true for NASA's space-based manipulators operating, for example, on Mars, as well as for inaccessible earth-based robots, such as those removing hazardous waste. Because the methods developed under this GSRP fellowship are software based, they need not be implemented (or even downloaded) until a failure has occurred or is anticipated. Thus, for low development and on-line equipment cost, the algorithms developed under this fellowship can be used to increase the likelihood of success of what are the most costly of robotic applications.

Published Work on the Fellowship Topic*

J.D. English and A.A. Maciejewski, "The Control of Kinematically Redundant Manipulators Anticipating Free-Swinging Joint Failures," *ANS 6th Topical Meeting on Robotics and Remote Systems,* pp. 480–486, Monterey, CA, Feb. 1995

J.D. English and A.A. Maciejewski, "Fault Tolerance for Kinematically Redundant Manipulators: Anticipating Free-Swinging Joint Failures," *IEEE International Conference on Robotics and Automation,* Minneapolis, MN, April 1996

J.D. English, "Robotic Workspaces after a Free-Swinging Failure," *US-Japan Graduate Student Forum, IEEE/RSJ International Conference on Intelligent Robots and Systems,* Osaka, Japan, November 1996

J.D. English and A.A. Maciejewski, "Euclidean-Space Measures of Robotic Joint Failures," *IEEE International Conference on Robotics and Automation,* Albuquerque, NM, April 1997

J.D. English and A.A. Maciejewski, "Robotic Workspaces after a Free-Swinging Failure," *Journal of Intelligent and Robotic Systems,* pp. 55-72, vol 19, 1997

J.D. English and A.A. Maciejewski, "Fault Tolerance for Kinematically Redundant Manipulators: Anticipating Free-Swinging Joint Failures," submitted to *IEEE Transactions on Robotics and Automation*

J.D. English and A.A. Maciejewski, "Measuring and Reducing the Euclidean-Space effects of Robotic Joint Failures," submitted to *IEEE Transactions on Robotics and Automation*

J.D. English and A.A. Maciejewski, "A Note on the Implementation of Velocity Control for Kinematically Redundant Manipulators," submitted to *IEEE Transactions on Systems, Man, and Cybernetics*

*An additional paper covering research on postfailure operation is yet to be submitted.

Awards

Finalist, best student paper at the 1996 *IEEE International Conference on Robotics and Automation*

American representative, *US-Japan Graduate Student Forum* (NSF sponsored)

Presentations on the Fellowship Topic

Paper presentation, *ANS 6th Topical Meeting on Robotics and Remote Systems,* 1995

Paper presentation, *IEEE International Conference on Robotics and Automation,* 1996

Paper presentation, *IEEE International Conference on Robotics and Automation,* 1997

Research presentation, *US-Japan Graduate Student Forum, IEEE/RSJ International Conference on Intelligent Robots and Systems,* 1996

Employment

James English is currently employed at the Hughes Missile Systems Company in Tucson, Arizona.